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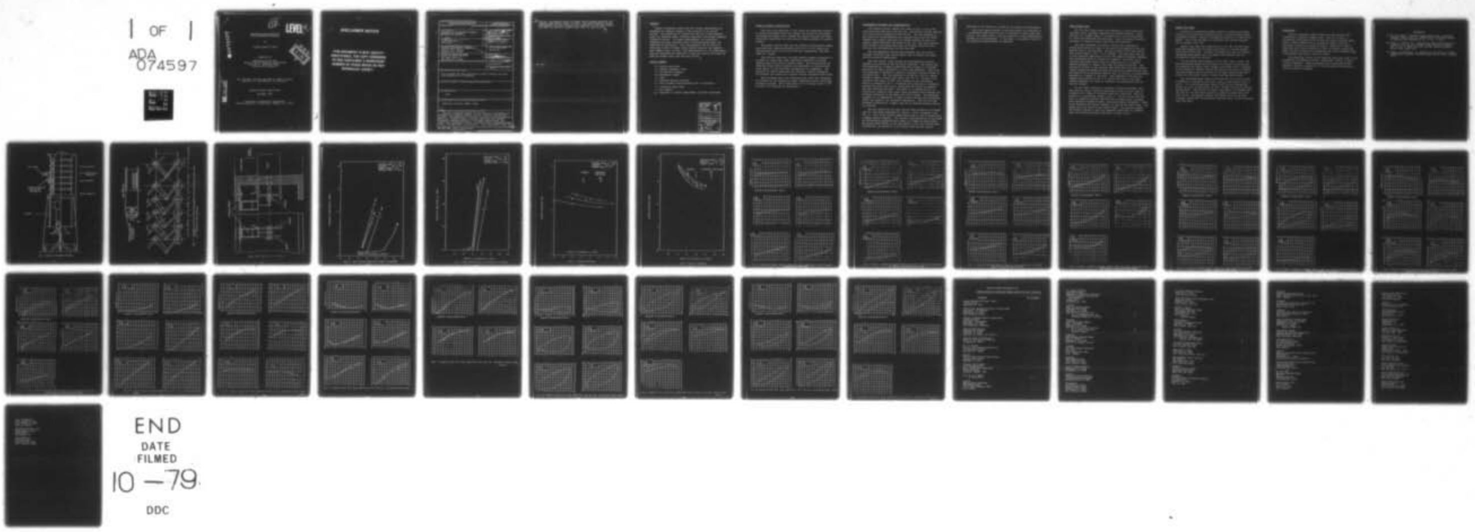

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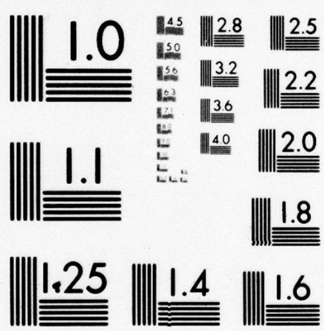
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RESEARCH ON THE FLUTTER OF
AXIAL-TURBOMACHINE BLADING

by

F. Sisto ~~and~~ M.F. Ward

Prepared for

Department of the Navy
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Typical aerodynamic moment and free flutter measurements are presented for negative stagger of thin airfoils in an annular cascade. The parameters of interest for the free flutter measurements are incidence angle, torsional amplitude, and reduced frequency (reduced velocity). For moment measurements, the significant parameters are mean incidence angle, interblade phase angle, and amplitude of oscillation. Since measurements take the

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ABSTRACT

Typical aerodynamic moment and free flutter measurements are presented for negative stagger of thin airfoils in an annular cascade. The parameters of interest for the free flutter measurements are incidence angle, torsional amplitude, and reduced frequency (reduced velocity). For moment measurements, the significant parameters are mean incidence angle, interblade phase angle, and amplitude of oscillation. Since measurements take the form of a continuous record of moment versus angular position, the symbolic name "moment loops" is used. The characteristics of the experimental data are discussed and comparison is made with earlier test data for positive stagger angle with the same airfoil.

LIST OF SYMBOLS

b = airfoil semi-chord

k = reduced frequency = $\omega b/V$

ω = oscillation frequency

M = aerodynamic moment

t = time

V = relative approach velocity

α_i = mean incidence angle measured from V to chordline

σ = interblade phase angle

ρ = air density

θ_o = amplitude of angular displacement (torsional amplitude)

SCOPE OF PRESENT INVESTIGATION

The work to be described in this report was undertaken basically to obtain experimental data for studying the flutter of thin blades with negative stagger and to compare the results obtained with those of previous experiments run with similar blades arranged for positive stagger.

The blades used for both the free flutter and quasistatic moment loop tests had a maximum thickness ratio of 4.7% with leading and trailing edge radii of 1/64 and 1/128 inch respectively, and with a chord of 2 inches.

Free flutter tests were run with negative stagger orientation in an effort to obtain data under conditions comparable to earlier compiled data with positive stagger angles. Data obtained with the identical blade profile geometry were published in a previous technical report (3) and have been included here for comparsion. The variation of flutter amplitude with different reduced frequencies and incident flow angles was of prime interest throughout these tests.

Mean incidence angle and interblade phase angle were parameters of interest for the quasistatic moment measurement tests with slowly oscillating blades. These tests were run at a stagger angle of -45° and with a 6° amplitude of oscillation.

EXPERIMENTAL APPARATUS AND INSTRUMENTATION

The Stevens vertical cascade rig, shown in Fig. 1, has a vertical axis with flow entry from the top. The entrance section consists of a conventional bellmouth and nose bullet. The main sections of the tunnel are interchangeable cast aluminum rings, with 20" inside diameter and similar rings with 16" outside diameter to form a 2" annular region throughout the length of the rig. Two inlet sections with variable inlet guide vanes cast out of epoxy direct the flow entering the instrumentation and test sections.

The instrumentation section which precedes the test section utilizes a yaw meter and a pitot-static tube to measure flow angle and flow velocity respectively.

The test section, which follows the instrumentation section, depends on the nature of the test being conducted. The section used for determination of moment coefficient data consists of 30 blades, each with its shaft terminated in a 4-bar link mechanism. This 4-bar link mechanism is designed to generate a harmonic torsional motion of the blade shaft. The link mechanism is driven by 4 low H.P. motors thorugh a number of small nylon gears (see Fig. 2). Because of the low RPM of the motors (2 RPM), the frequency of the oscillatory motion is essentially zero. Interblade phase angle may be changed by removing the nylon idler gears, positioning the blades accordingly, and then replacing the gears. The shaft of a selected airfoil is fitted with a special strain gage torque transducer which measures the torsional deflection of the shaft and airfoil system. The positional variable (θ) is supplied by a linear variable differential transformer (LVDT) and linked to the torsional displacement. Thus with all the necessary calibrations, a moment loop can be produced directly with an x-y recorder.

The test section for the free flutter tests consists of 30 blades, each with its shaft terminated by a spring - airpot arrangement (see Fig. 3). Thus in the flutter regime each blade is free to vibrate with a damped natural frequency. The vibration characteristics of the blades are determined by mounting strain gages on a number of spring posts. The spring posts deflect in the same manner as the link, and for small oscillations, the spring is in its linear range and thus flutter

amplitude of the blades are related to the spring post deflections.

The strain gages attached to the spring posts are connected to a resistance bridge which in turn is connected to strain gage indicators. The output signal from the indicators is then amplified and recorded on an oscillograph. In this manner, a permanent record of the vibration characteristics is obtained.

FREE FLUTTER TESTS

For the free flutter tests the parameters of significance were incidence angle, torsional amplitude and reduced frequency. Tests were run at a stagger angle of -45 degrees for various combinations of inlet flow velocities and directions. Tests at constant velocity and tests at constant flutter amplitudes were conducted.

The tests conducted at constant velocity were obtained by adjusting the inlet air rings in the nose of the apparatus until the desired velocity was obtained. The significance of the free flutter test results shown in Fig. 4 is as follows. The plot shows that for a given torsional amplitude of flutter the reduced frequency increases with increasing angle of incidence as expected. The slope of the torsional amplitude versus angle of incidence line at a constant reduced frequency is steeper, the lower the reduced frequency. The scattering of data at low torsional amplitudes would not only indicate "noisy" boundaries between flutter and non-flutter conditions but also the possibility of hysteresis effects, that is, flutter is directionally dependent on a number of variables. When compared to the positive stagger angle results in Fig. 5 it can be seen that for the same reduced frequency, the angle of incidence is significantly less for negative stagger.

For the tests conducted at constant torsional amplitudes, data were taken to obtain torsional amplitudes as close to each other as possible over a range of incidence angles and velocities. Data are plotted in a conventional manner in Fig. 6. As can be seen from the plot, at constant torsional amplitude the incidence angle increases with decreasing reduced velocity (increasing reduced frequency). These plots delineate the flutter boundary, as shown by the solid lines. The region above the lines is the flutter region. For negative stagger the reduced velocity is less for comparable conditions of incidence angle and constant torsional amplitude, as seen in Fig. 7.

MOMENT LOOP TESTS

Variation of aerodynamic moment acting on a slowly oscillating airfoil is of significant importance since it allows studying static aerodynamic effects, effects of neighboring airfoils in a qualitative manner. Due to the low speed of oscillation the reduced frequency may be assumed to be zero.

Moment loop tests were conducted at 0, 60, 120, and 180° interblade phase angles with the blade oscillating at -45° mean stagger angle with 6° amplitude. Variation of moment loop area with various interblade phase angles are in agreement with previous data and the physical nature of stalling.

For interblade phase angles of 0° and 180°, Figs. 8 and 9, the work encountered during the oscillation of one cycle is nearly zero and therefore the moment loops collapse into single lines. Backlash in the mechanical linkages and the deviation of the four-bar linkage from pure harmonic motion account for the small enclosed area associated with the moment loops at these interblade phase angles.

For interblade phase angles of 60° and 120° the critical nature of phasing is revealed by the larger loops at these angles, Figs. 10 and 11. At an interblade phase angle of 60° the work encountered during one cycle of oscillation is near a maximum as noted by previous investigators. Similarities in moment loop shapes are observed from the data for the same blade geometry at positive stagger angle 45°, Figs. 12-15. Corresponding moment loop shapes occur at the same incidence angles when two successive rotations about the two coordinate axes take place.

CONCLUSIONS

A set of quasistatic moment loops have been measured and recorded for a negative stagger angle. This set of data, in conjunction with previous sets of data for positive stagger angle, gives a fairly complete set of quasistatic moment loops for a particular airfoil in an annular cascade. These can be used to study the stall flutter behavior at very low reduced frequencies. They can also be utilized in predictions for finite frequency loops using methods described in previous reports.

The scattering of data at low torsional amplitudes leads to the possibility of hysteresis effects, which means, flutter is directionally dependent. Negative stagger angle configurations have become of interest recently due to flutter problems developing in the rear stages of turbines.

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(1) Shioiri, Jumpei, "Non-Stall Normal Mode Flutter in Annular Cascade", Parts I and II, Transactions of the Japan Society of Aeronautical Engineering, Vol. 1, No. 1, 1958.

(2) Sisto, F. and Ni, R.H., "Quasistatic Moment Measurements for Airfoils in an Annular Cascade," AIAA Journal of Aircraft, Vol. 9, No. 4, April 1972, pp. 298-305; Technical Report ME RT 71002, April 1971.

(3) Sisto, F. and Rossin, R., "Research on the Flutter of Axial-Turbomachine Blading", Technical Report ME RT 78004, November 1978.

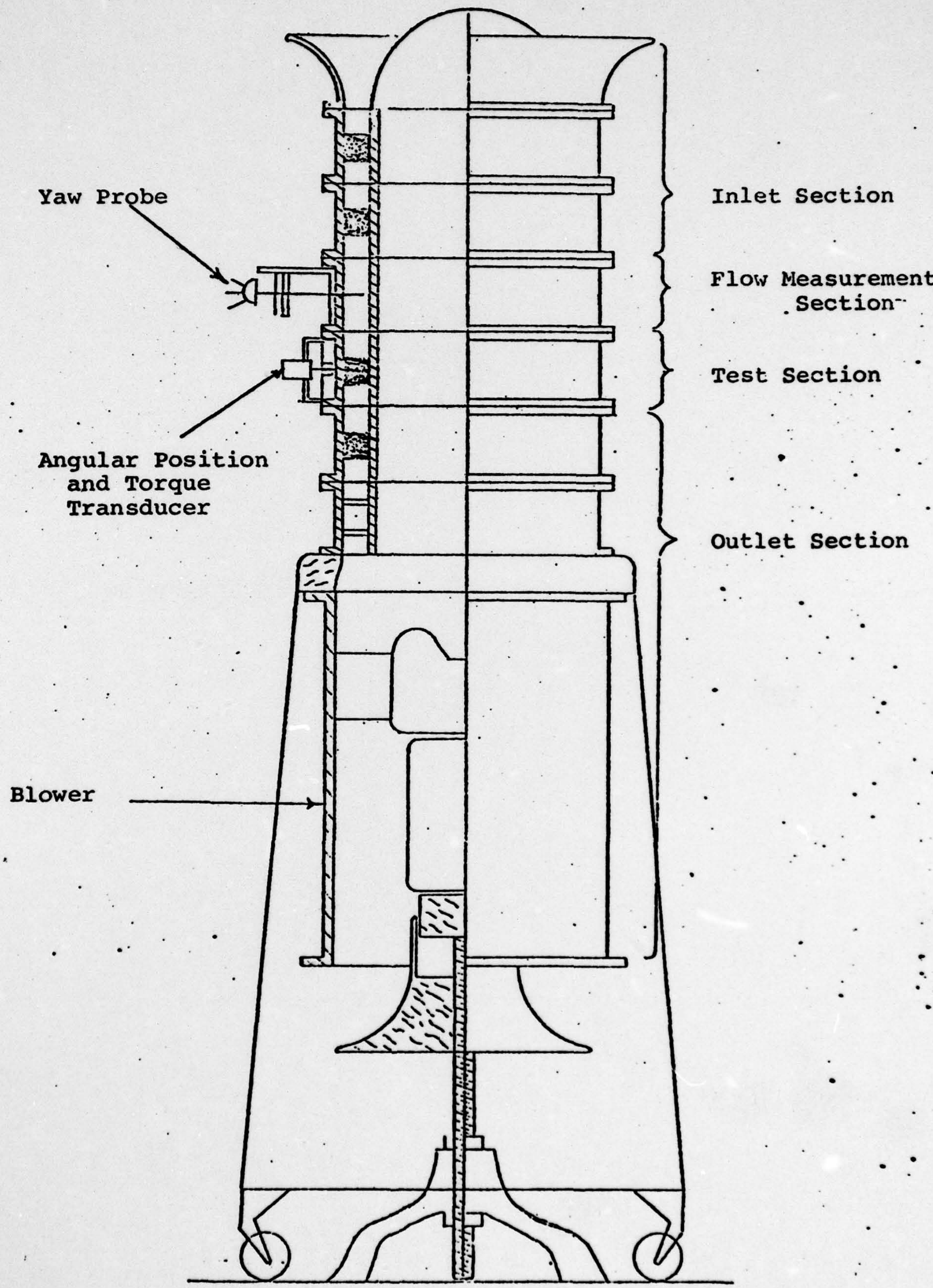
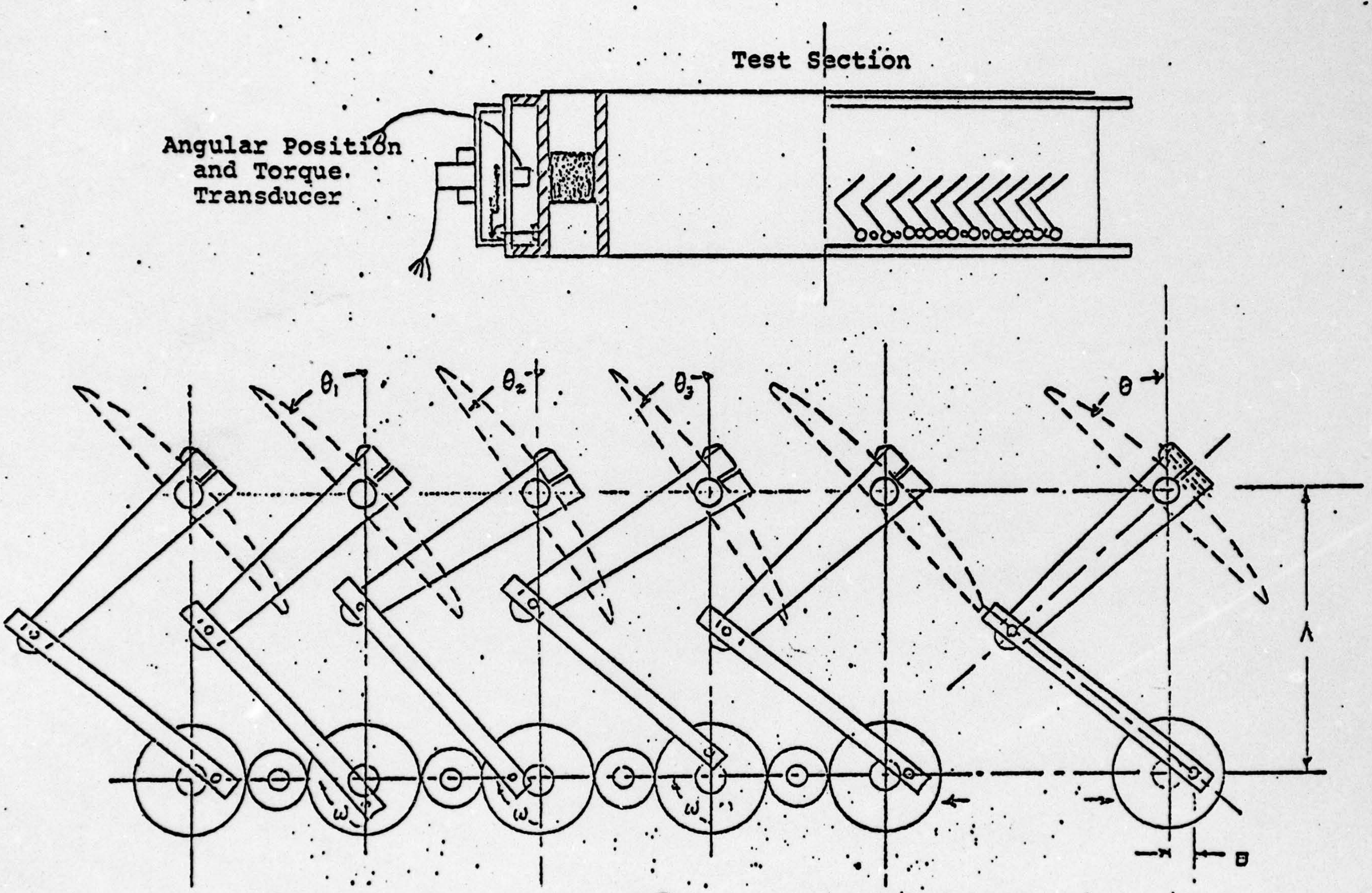


Fig. 1 General Assembly Drawing



$\Theta_1 \cong \Theta_1 \cos(\omega t) \quad \Theta_2 \cong \Theta_o \cos(\frac{\pi}{2} + \omega t) \quad \Theta_3 \cong \Theta_o \cos(\pi+\omega t) \qquad A >> B, \ \Theta = \Theta_o \cos(\omega t$

Fig. 2 Linkages and Gear Train Arrangement for Sinusoidal Motion with 90° Interblade Phase Angle.

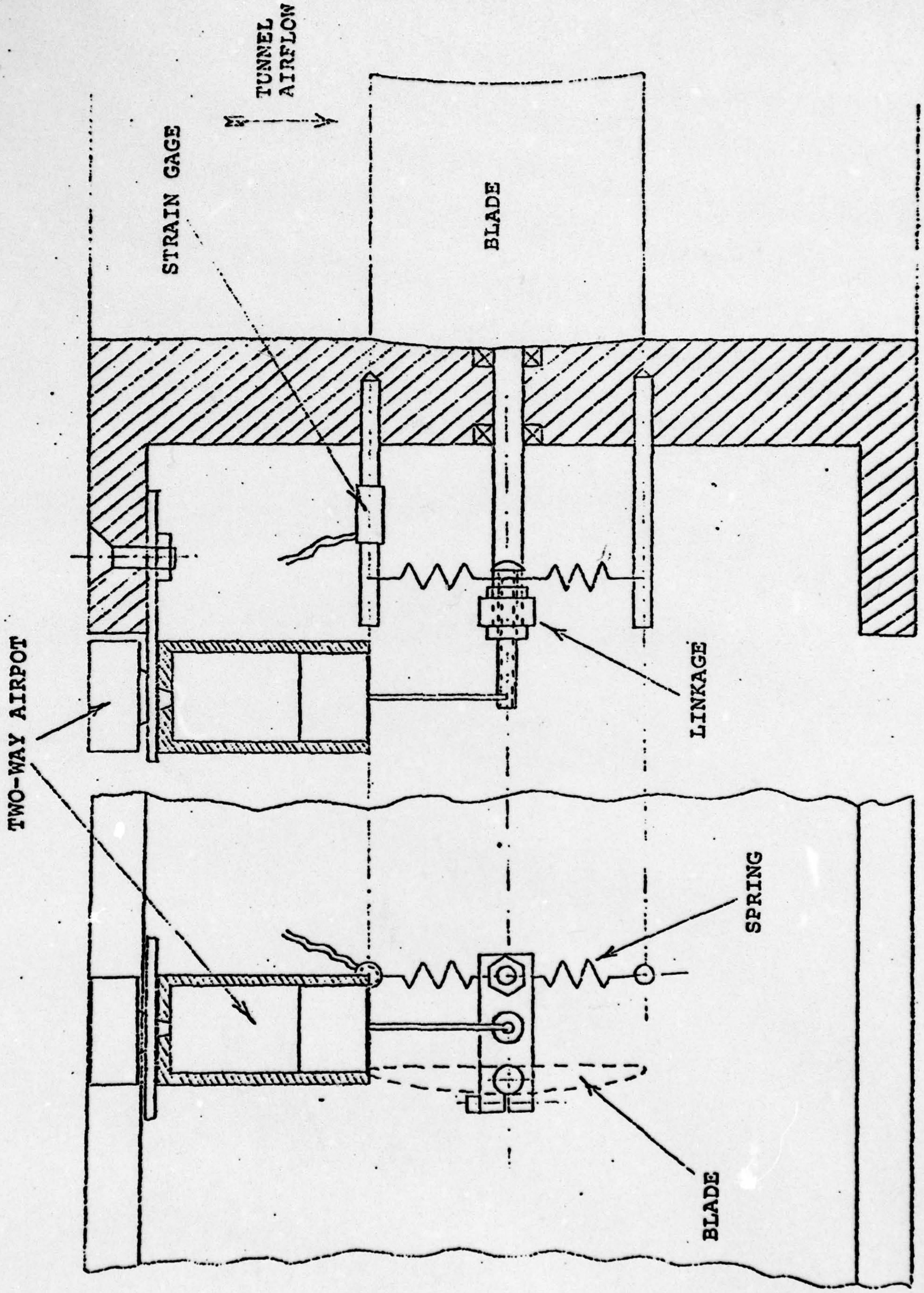


Fig.3 Free Flutter Test Section

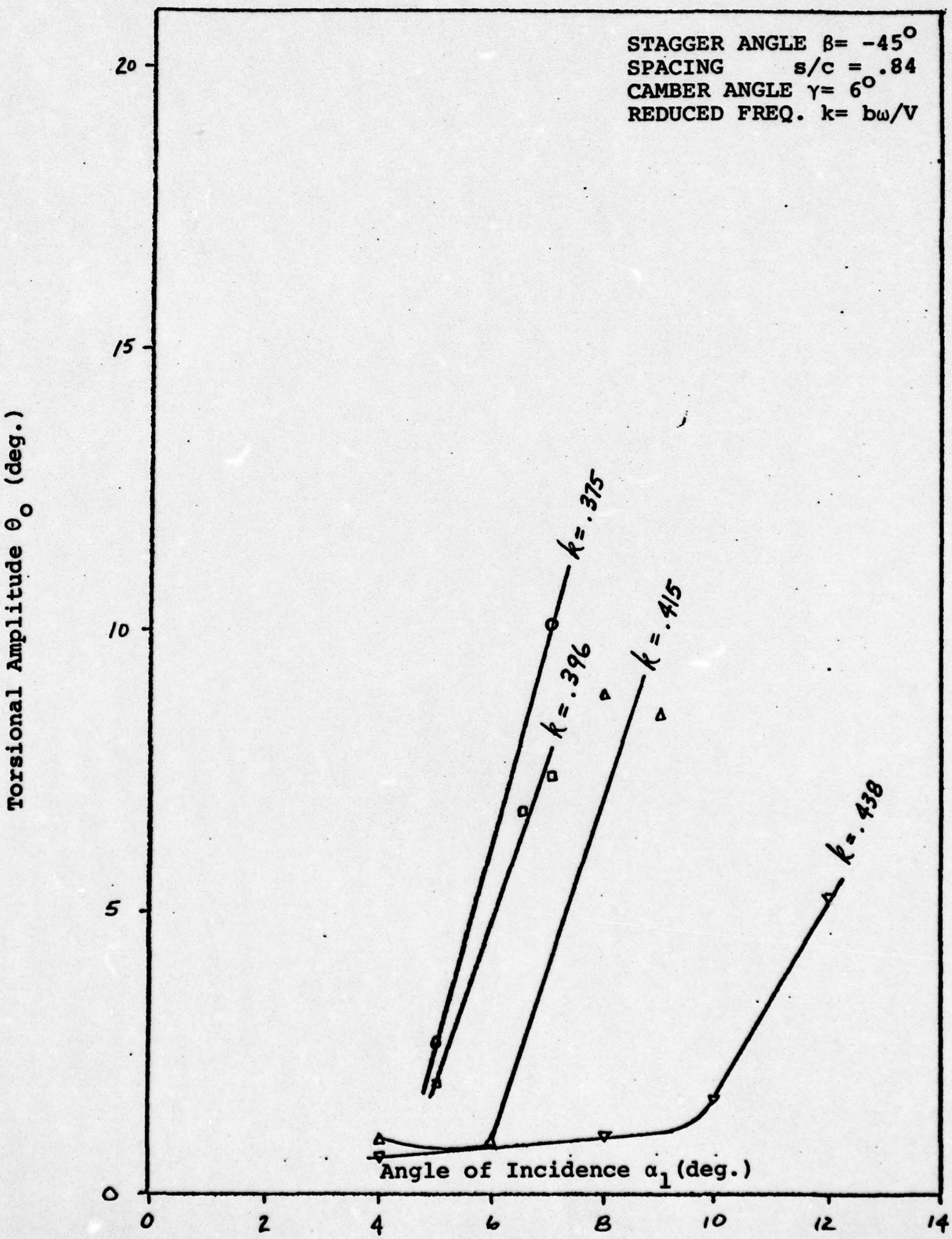


Fig. 4 Free Flutter Tests for Blades in Cascade

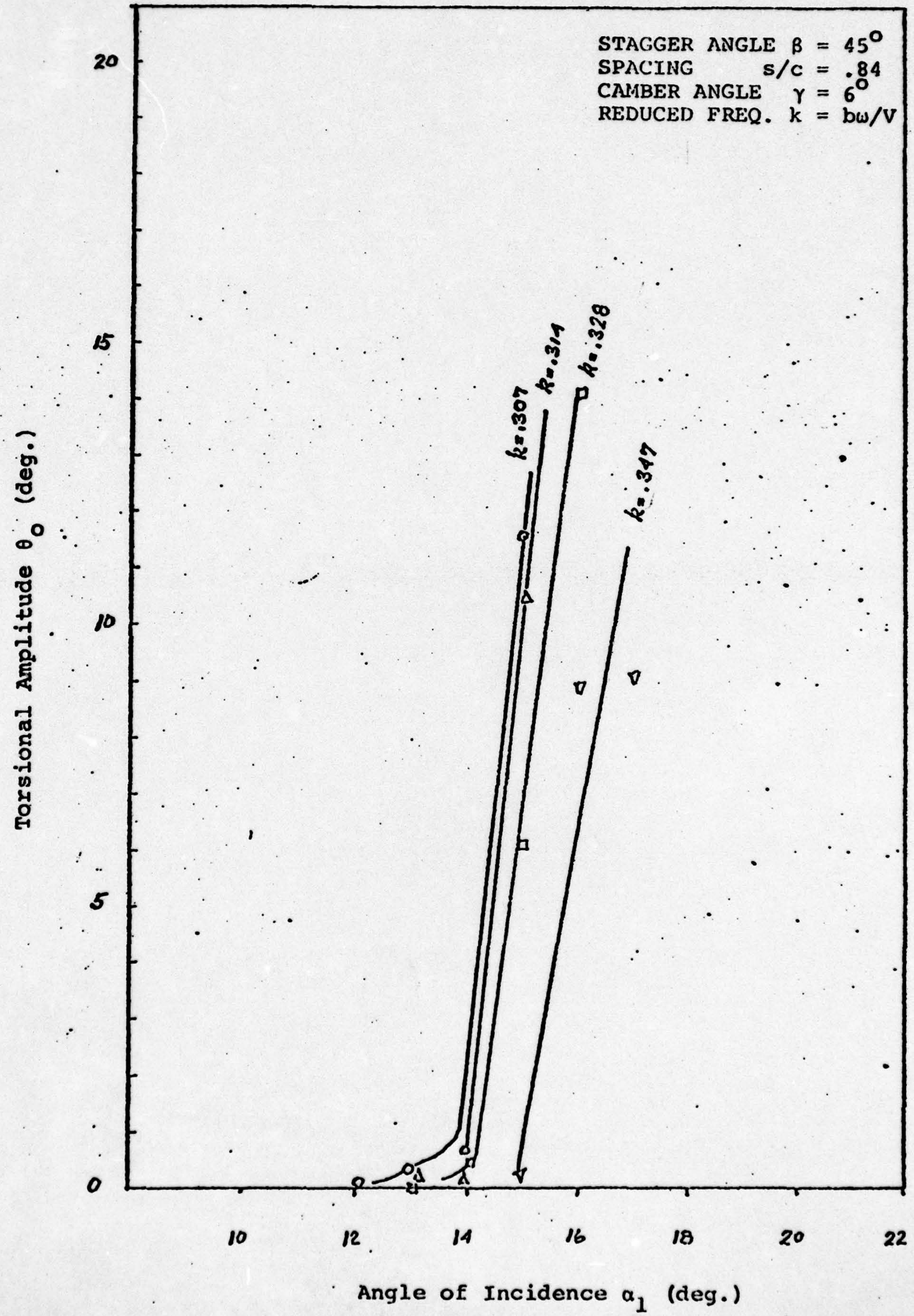


Fig. 5 Free Flutter Tests for Blades in Cascade

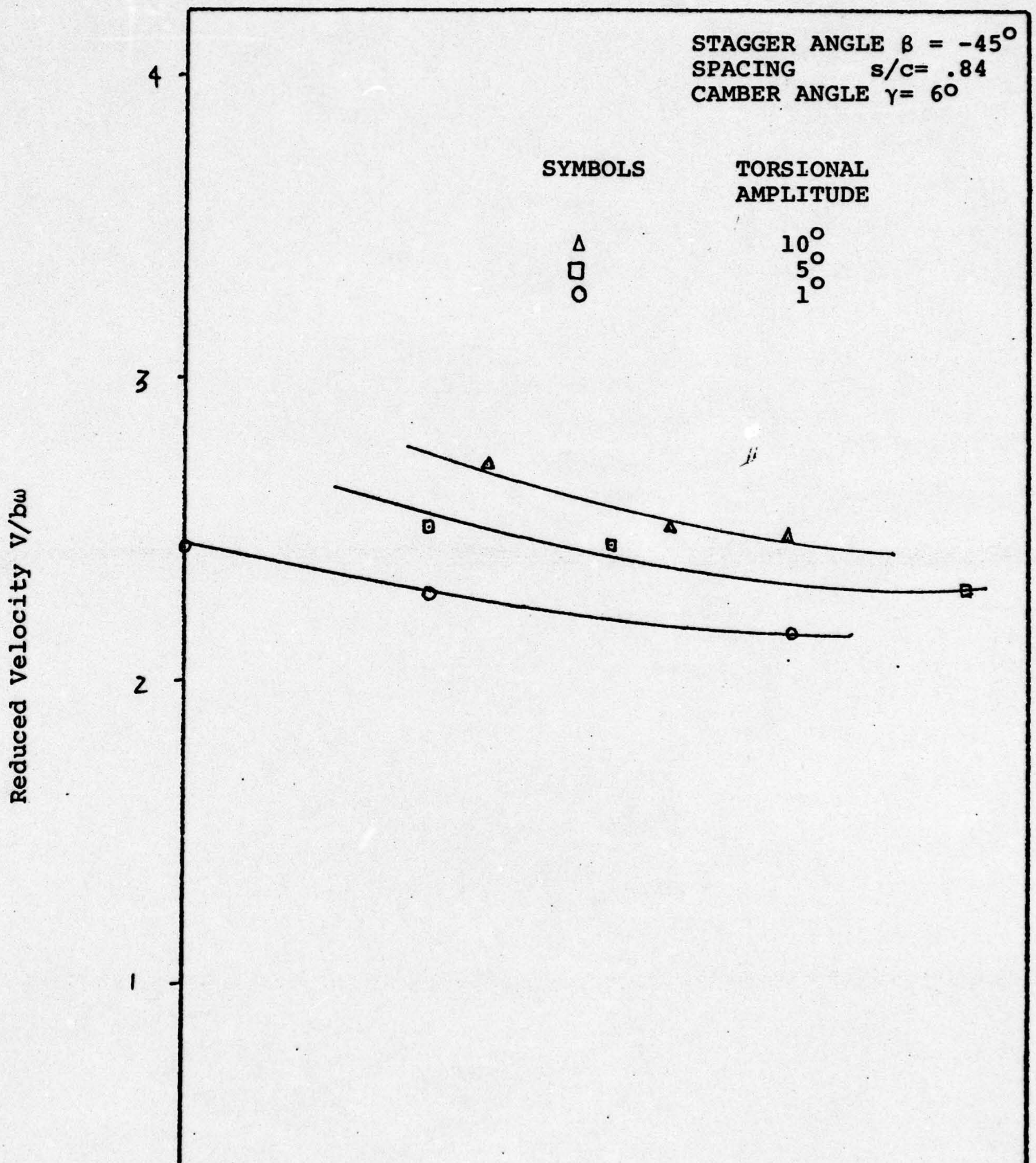


Fig. 6 Flutter Boundary

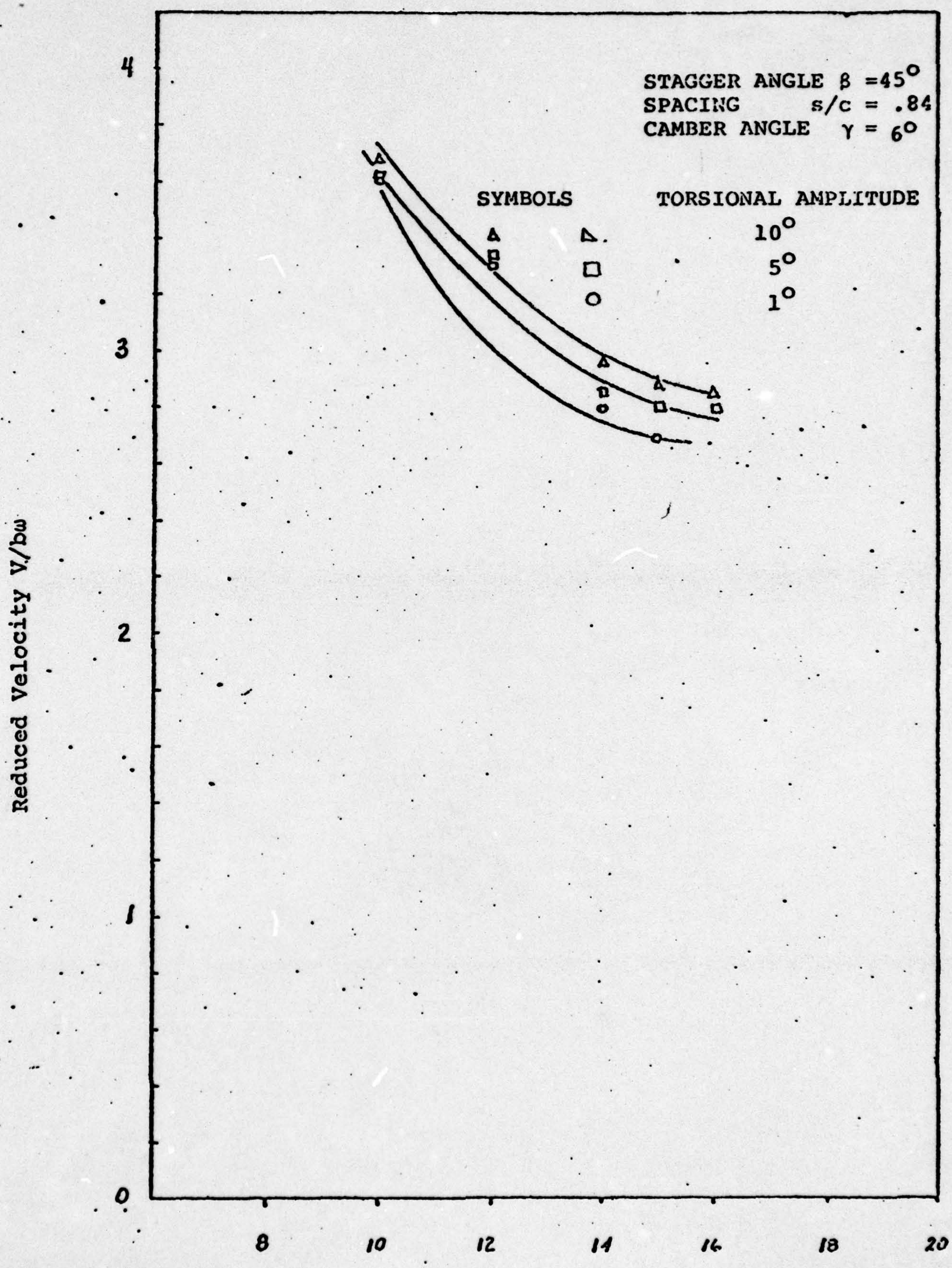


Fig. 7 Flutter Boundary

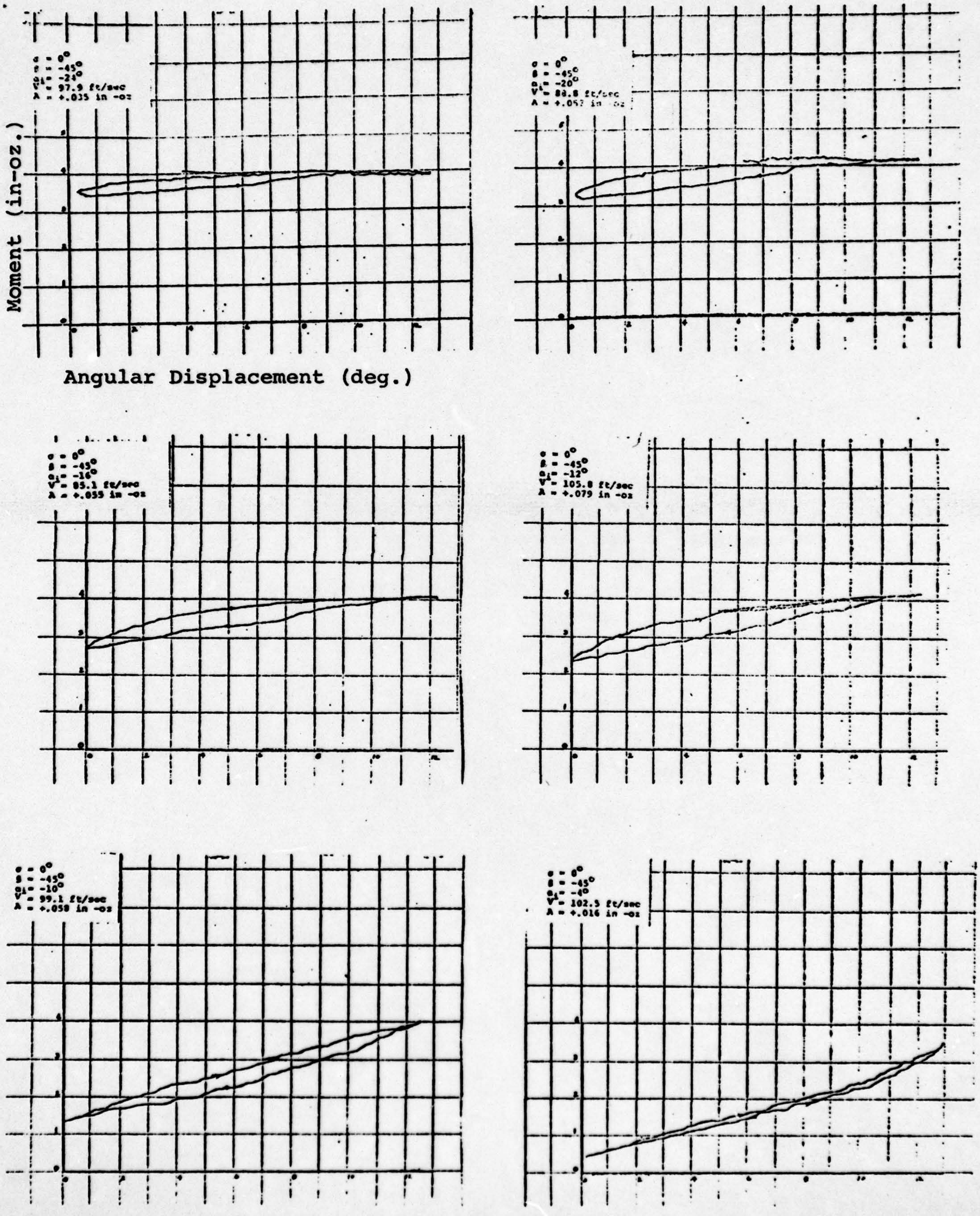


Fig. 8 Negative Stagger Moment Loops for Large Amplitude with 0° Degree Interblade Phase Angle

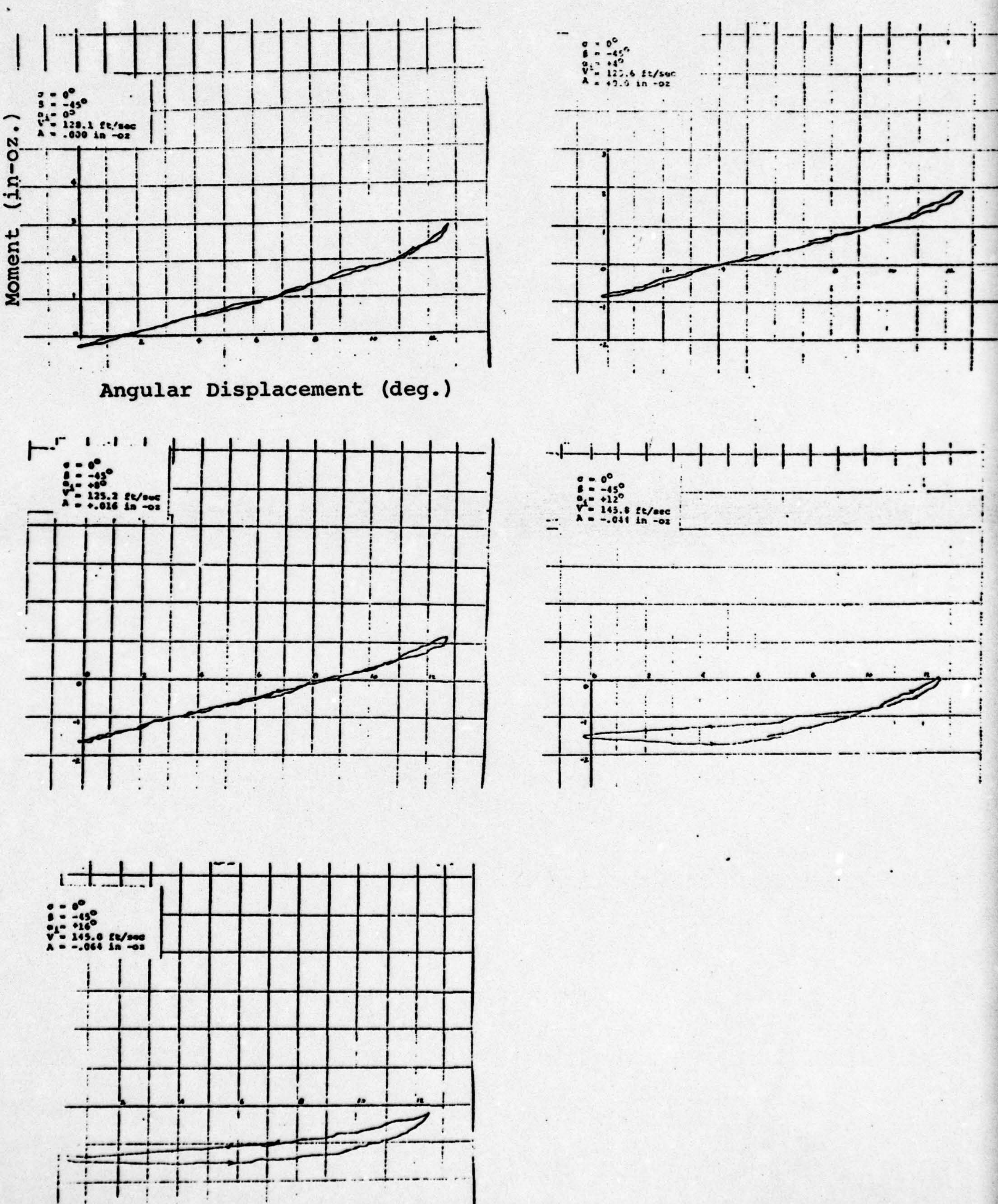


Fig. 8 (cont.) Negative Stagger Moment Loops for Large Amplitude with 0° Degree Interblade Phase Angle

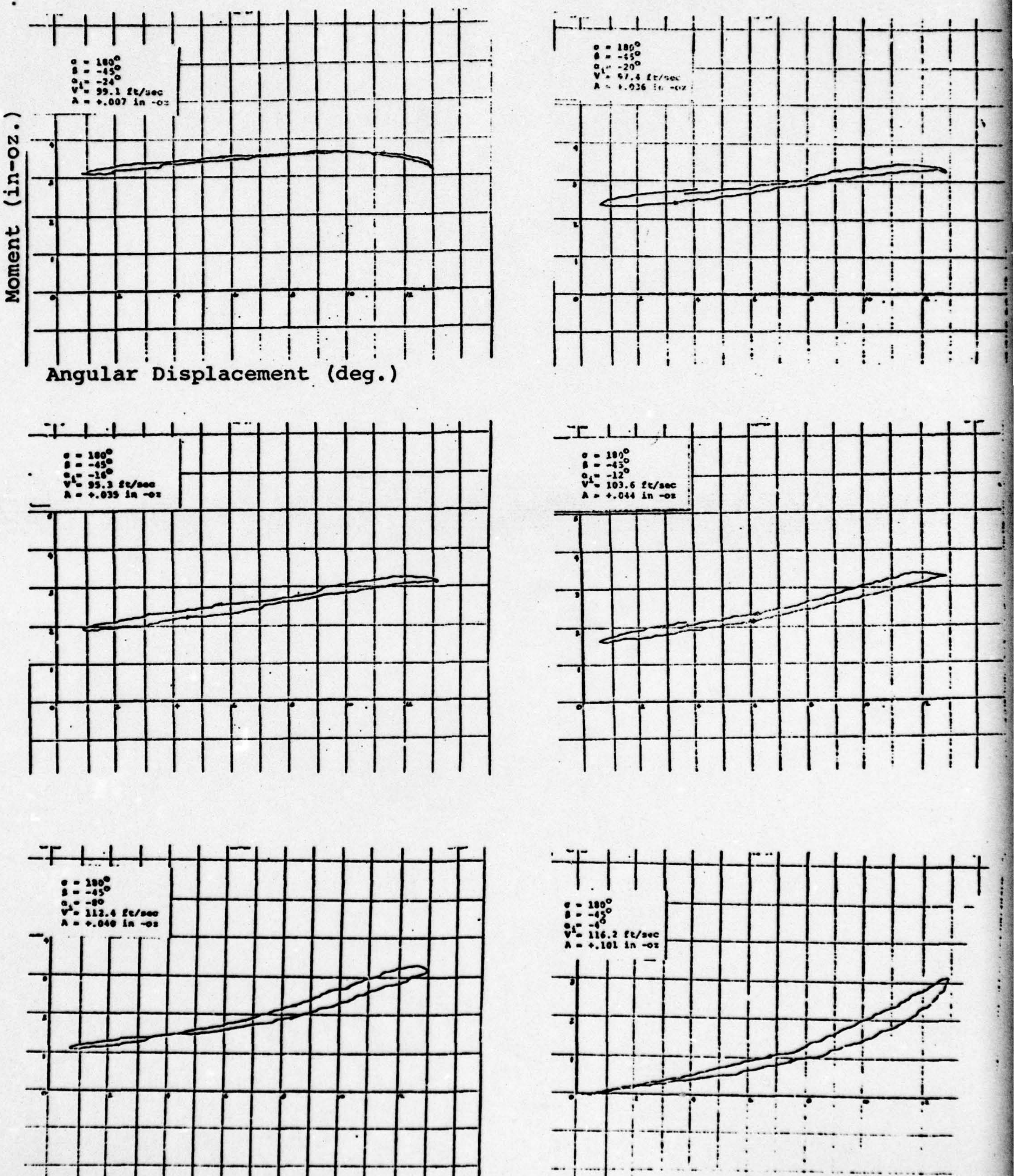


Fig. 9 Negative Stagger Moment Loops for Large Amplitude with 180° Degree Interblade Phase Angle

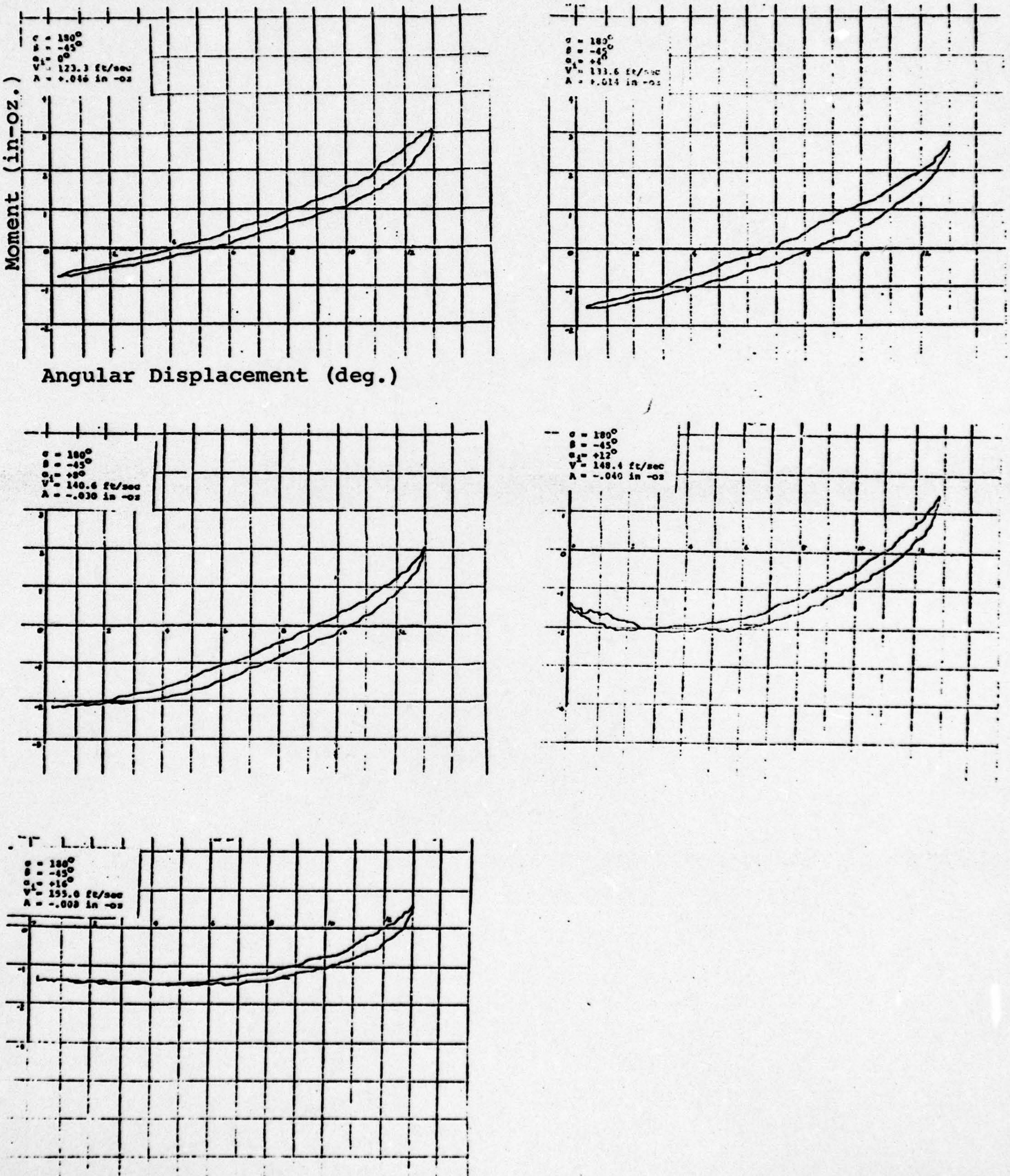


Fig. 9 (cont.) Negative Stagger Moment Loops for Large Amplitude with 180° Degree Interblade Phase Angle

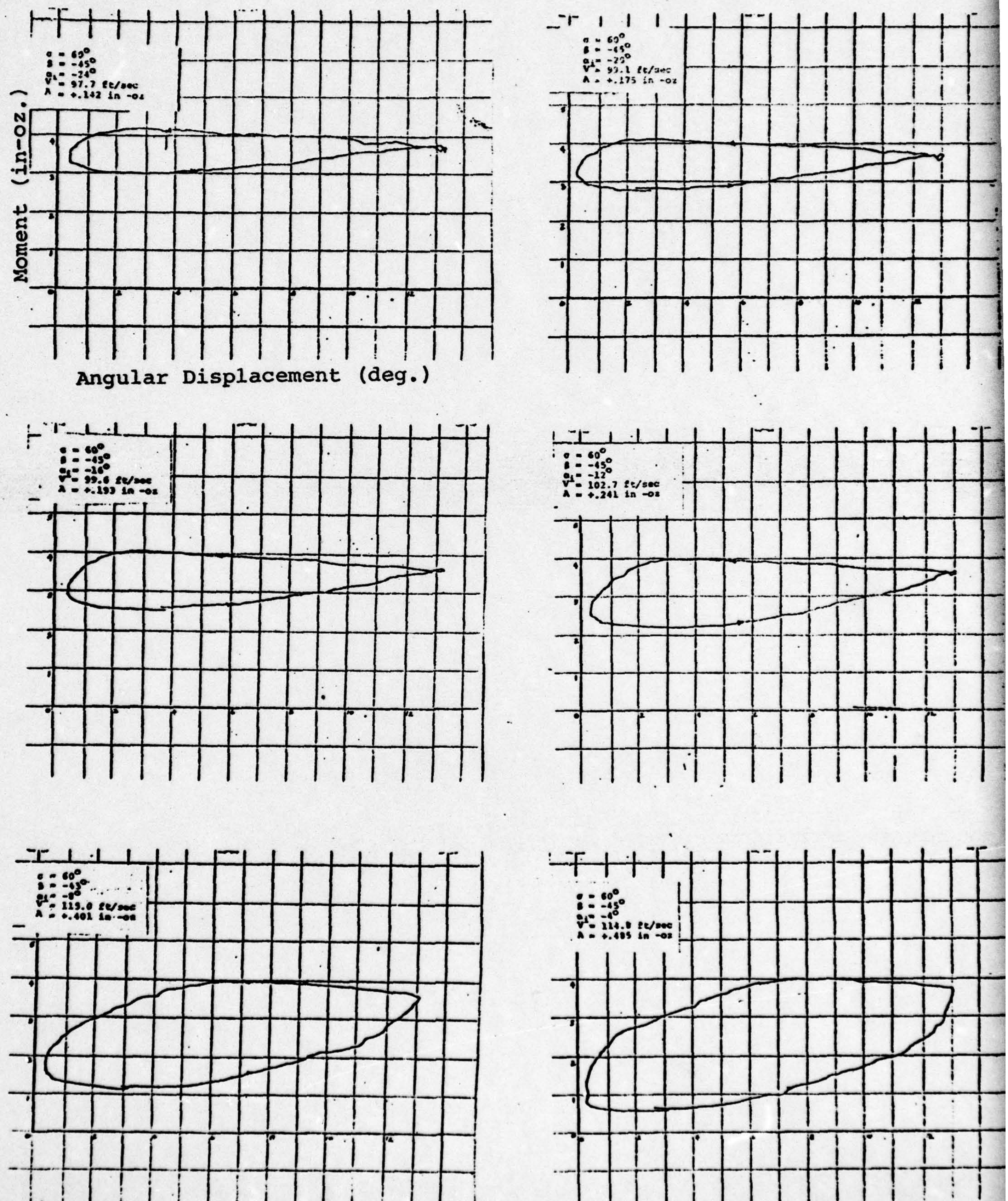
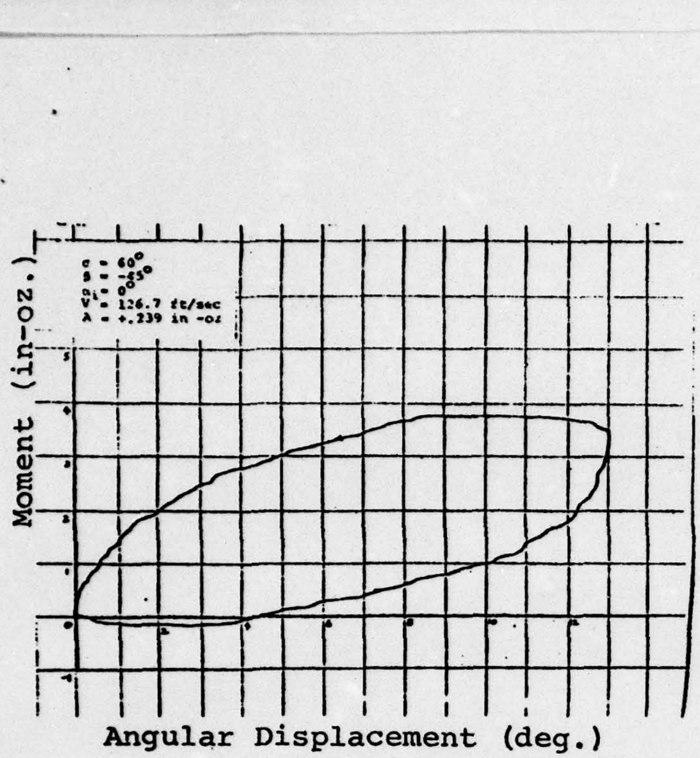
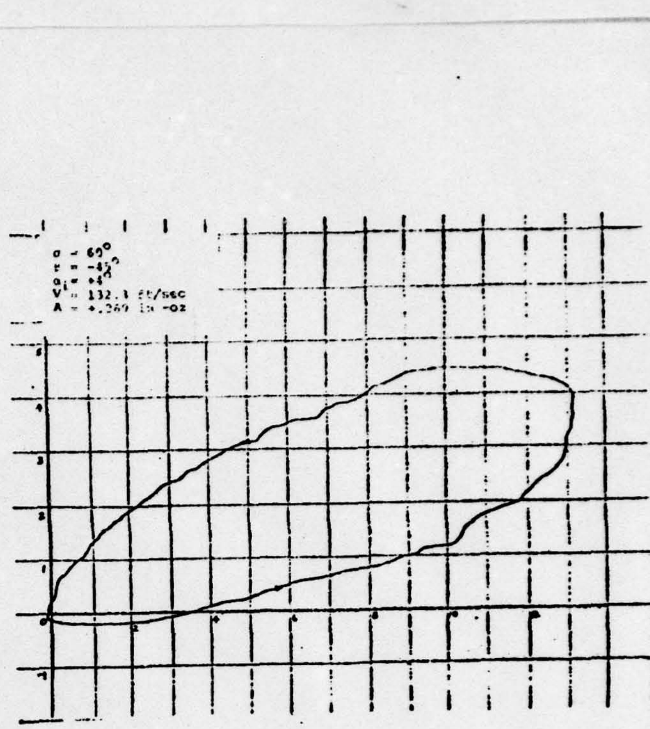
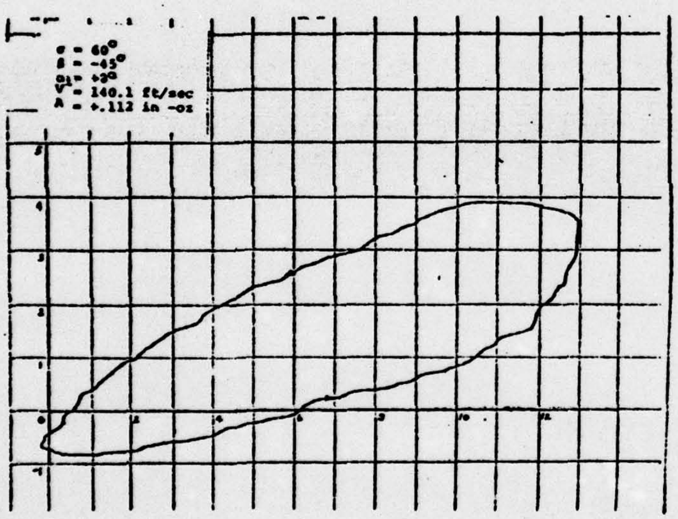
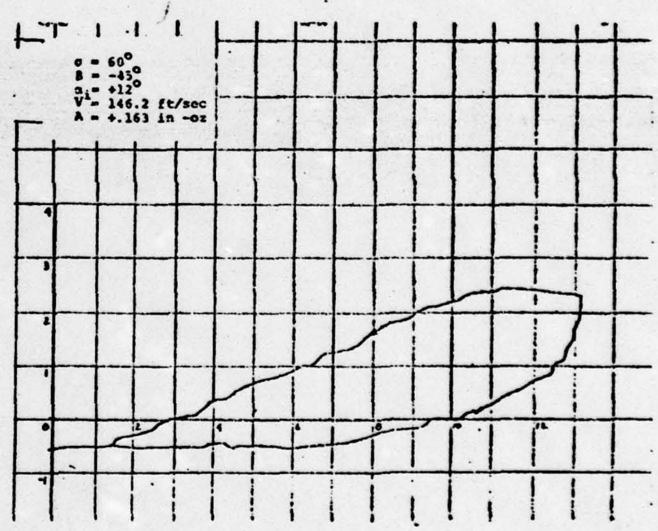


Fig. 10 Negative Stagger Moment Loops for Large Amplitude with 60° Degree Interblade Phase Angle









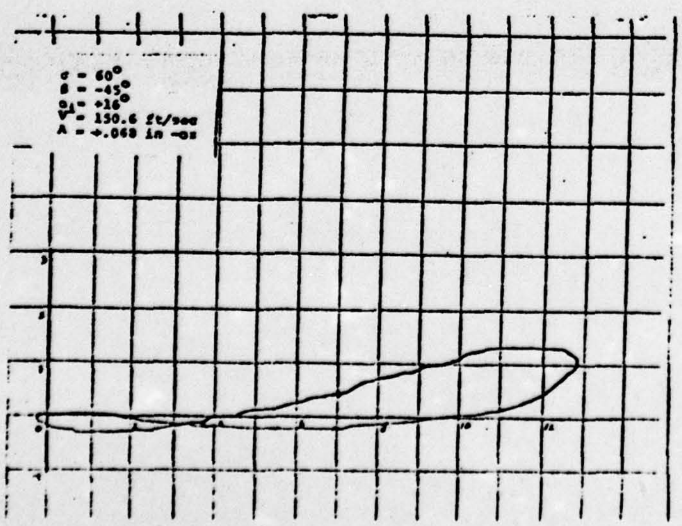


Fig. 10 (cont.) Negative Stagger Moment Loops for Large Amplitude with 60° Degree Interblade Phase Angle

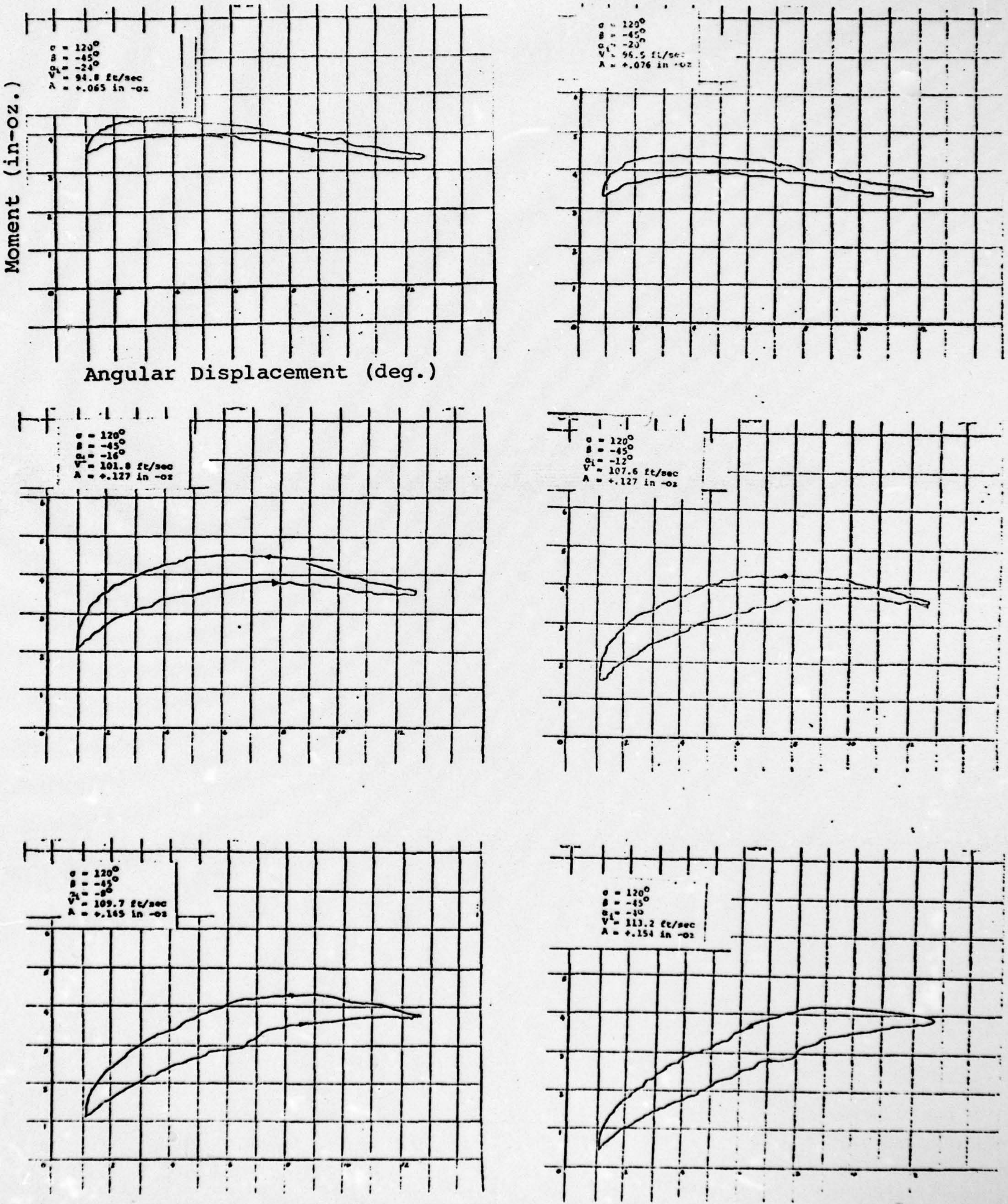


Fig. 11 Negative Stagger Moment Loops for Large Amplitude with 120° Degree Interblade Phase Angle

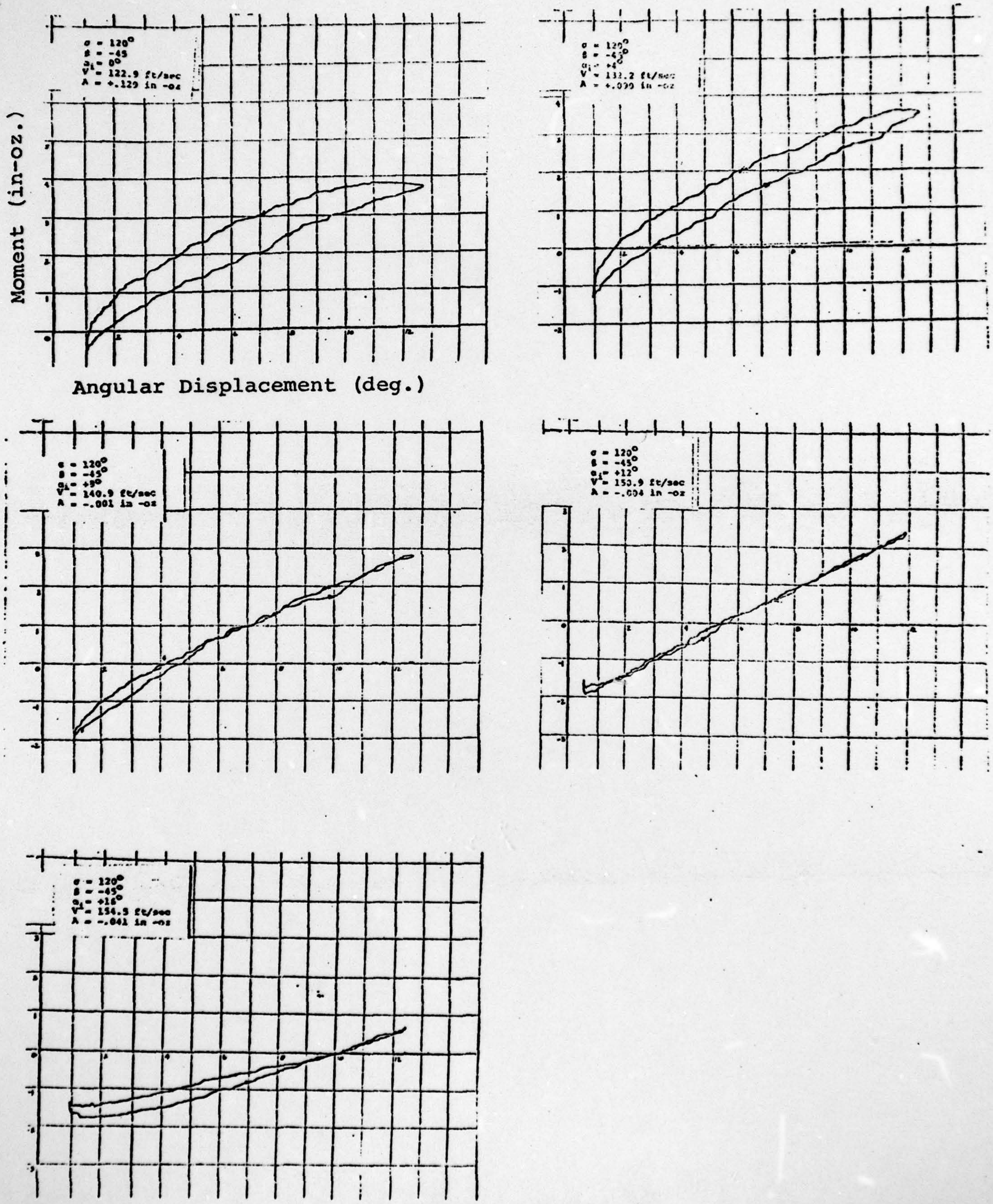


Fig. 11 (cont.) Negative Stagger Moment Loops for Large Amplitude with 120° Degree Interblade Phase Angle

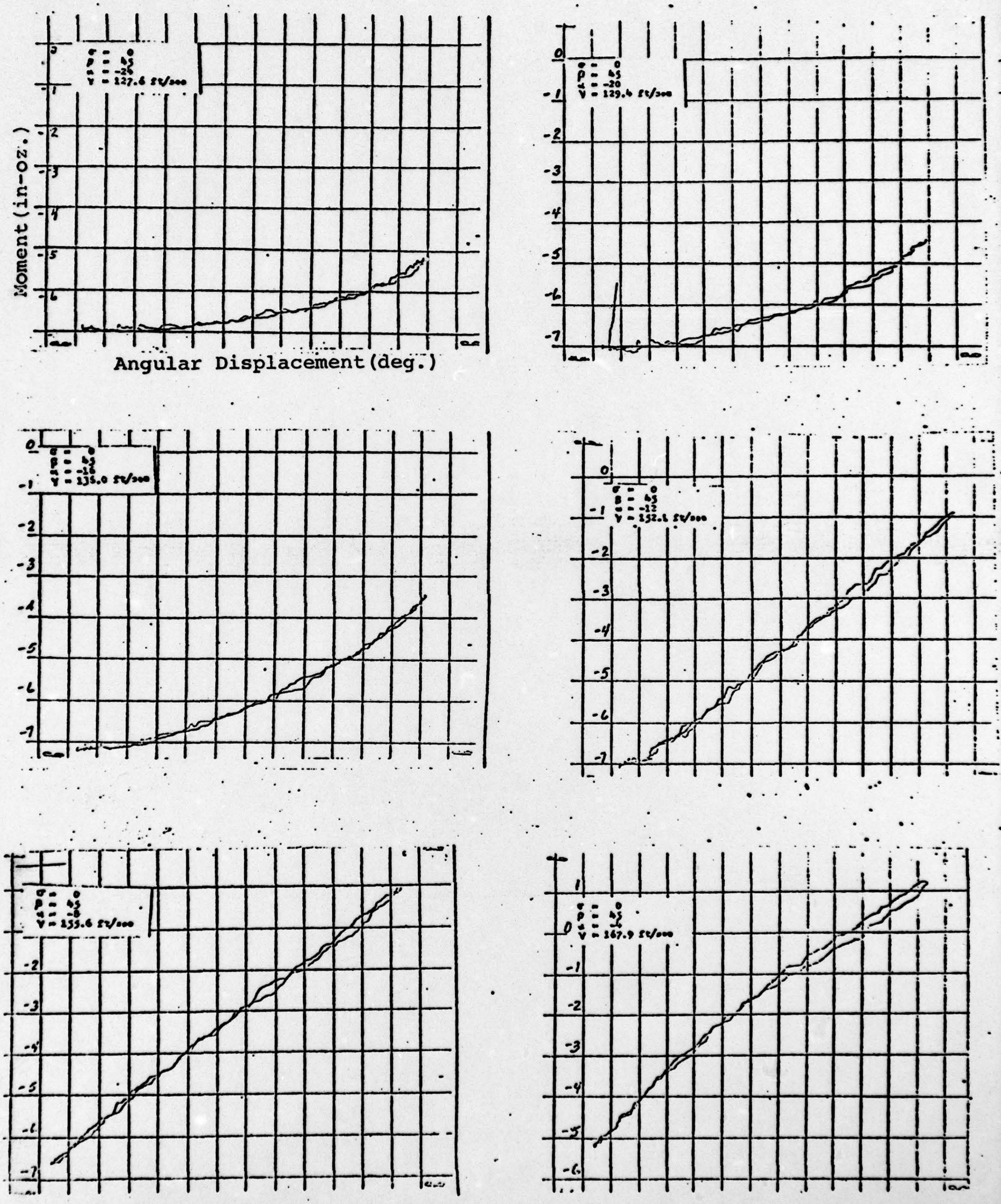


Fig. 12 Moment Loops for Large Amplitude with 0 deg. Interblade Phase Angle

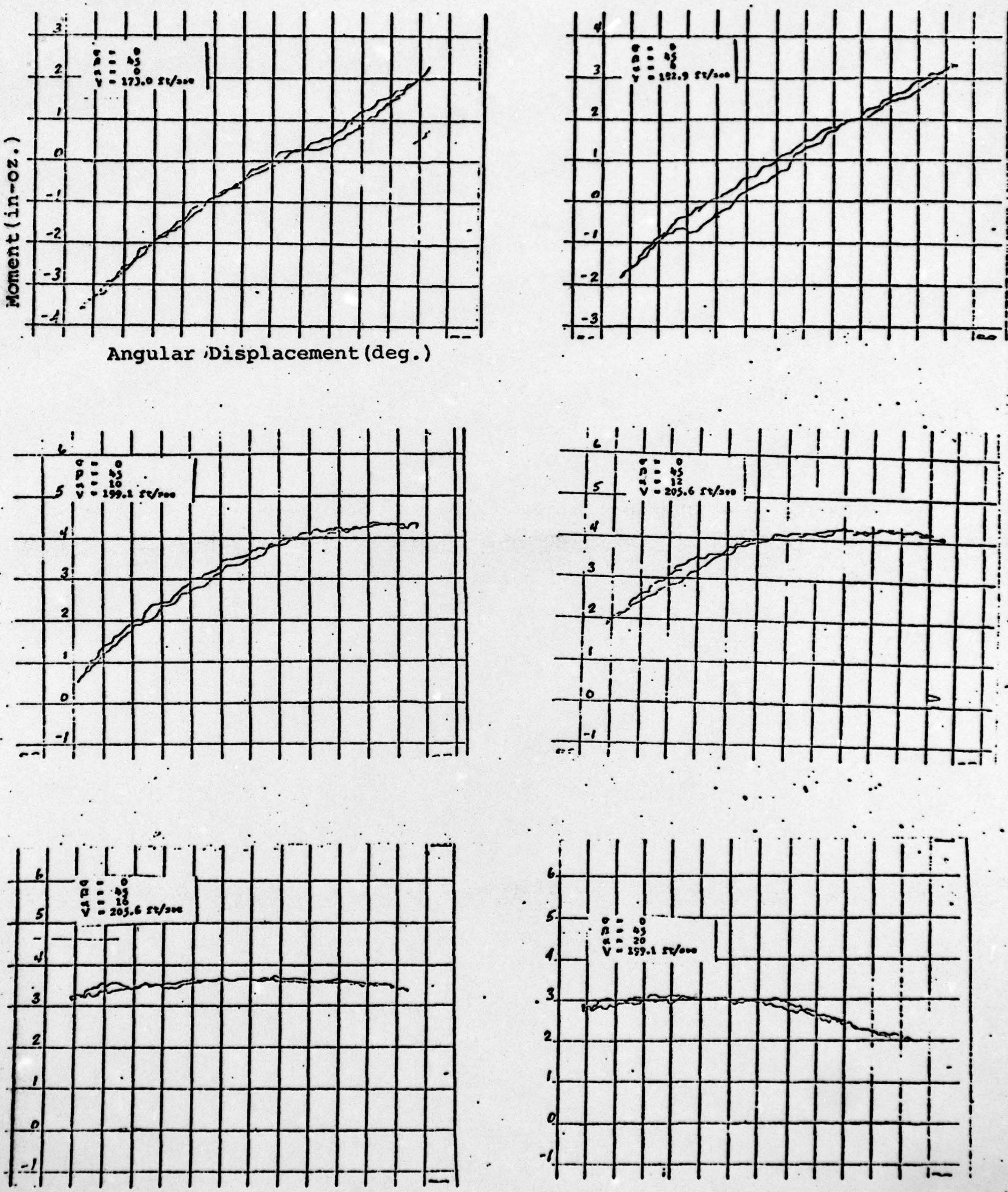


Fig. 12 Moment Loops for Large Amplitude with 0 deg. Interblade Phase Angle (cont.)

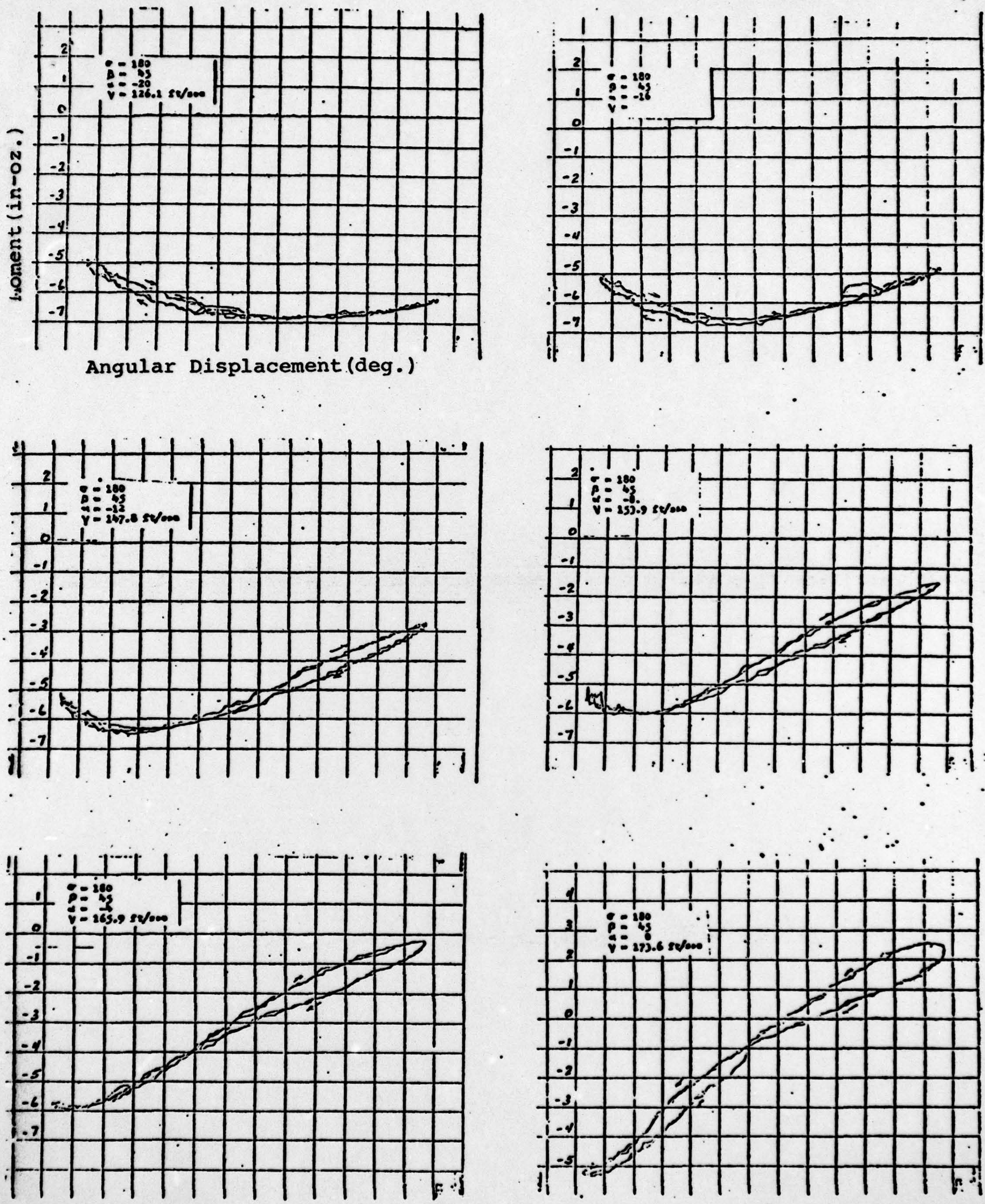


Fig. 13 Moment Loops for Large Amplitude with 180 deg. Interblade Phase Angle

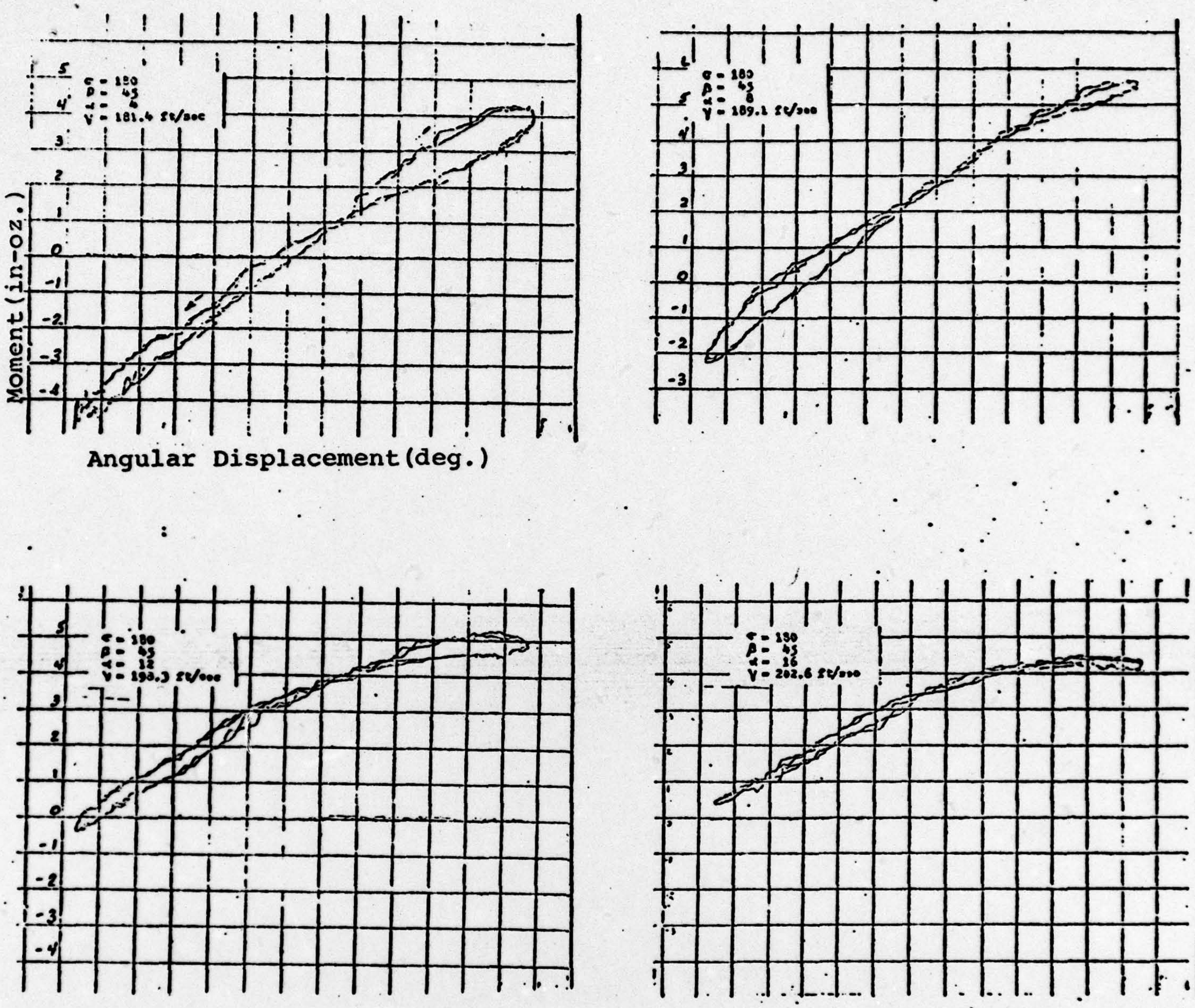


Fig. 13 Moment Loops for Large Amplitude with 180 deg. Interblade Phase Angle (cont.)

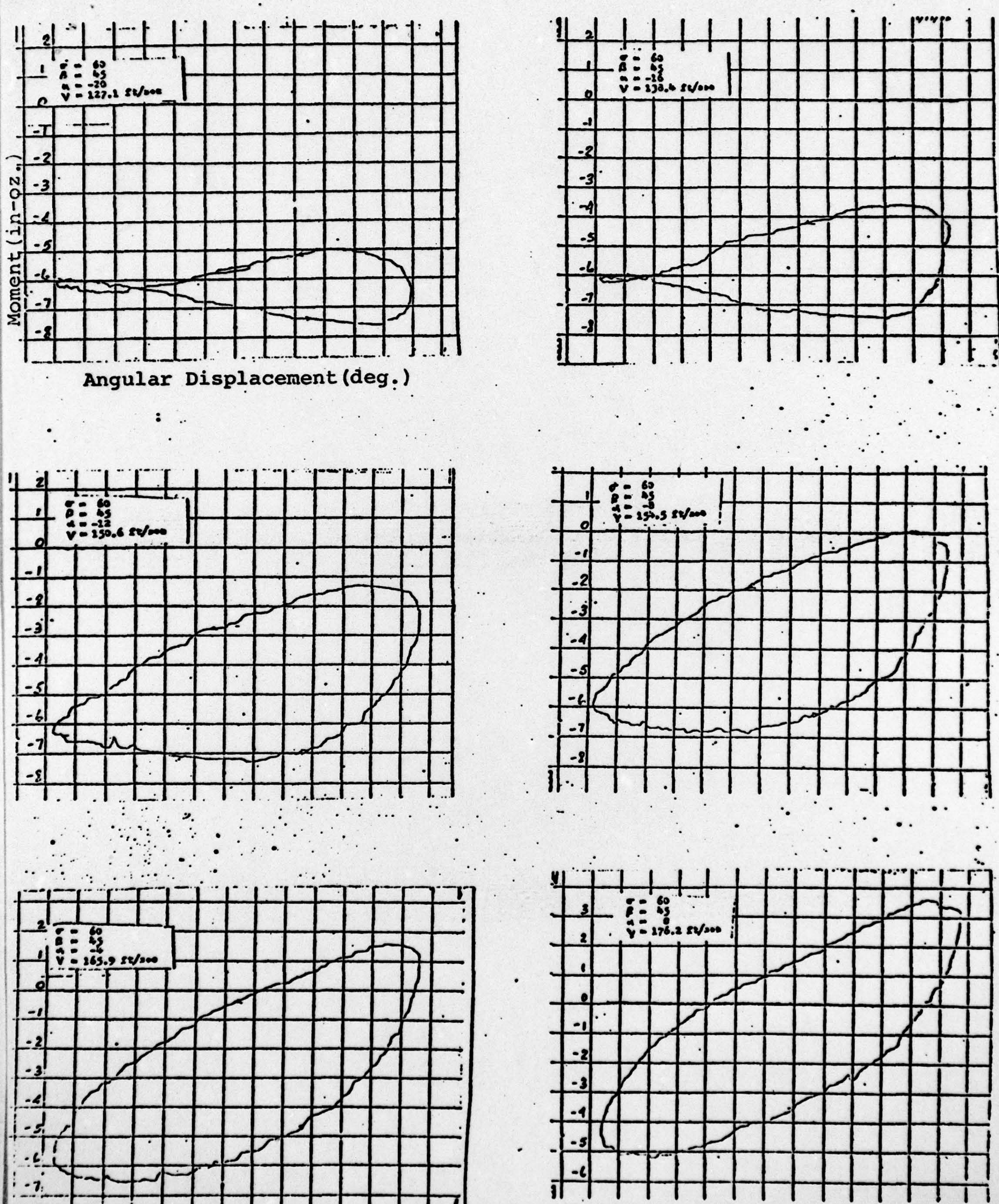


Fig. 14 Moment Loops for Large Amplitude with 60 deg. Interblade Phase Angle

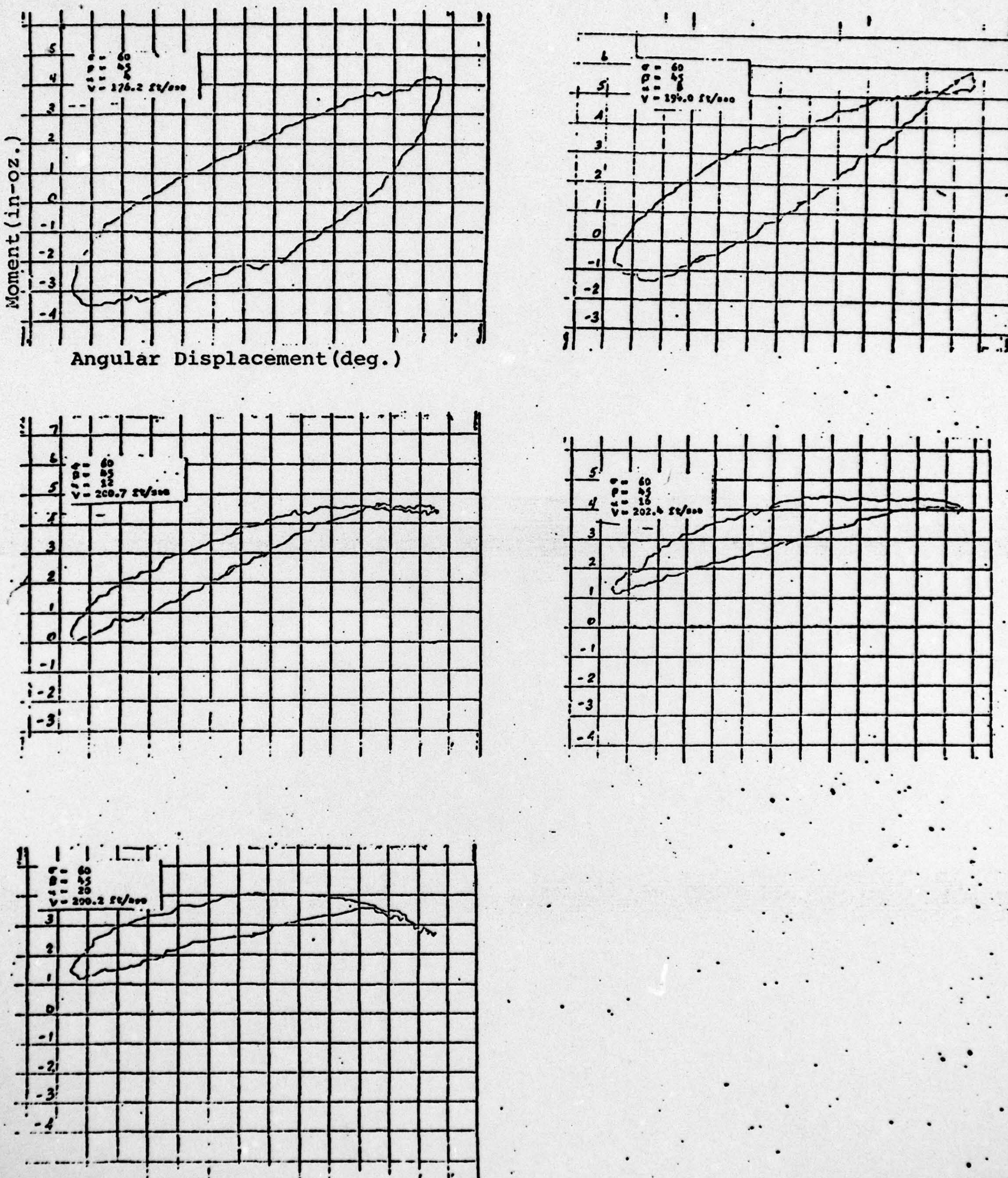


Fig.14 Moment Loops for Large Amplitude with 60 deg. Interblade Phase Angle (cont.)

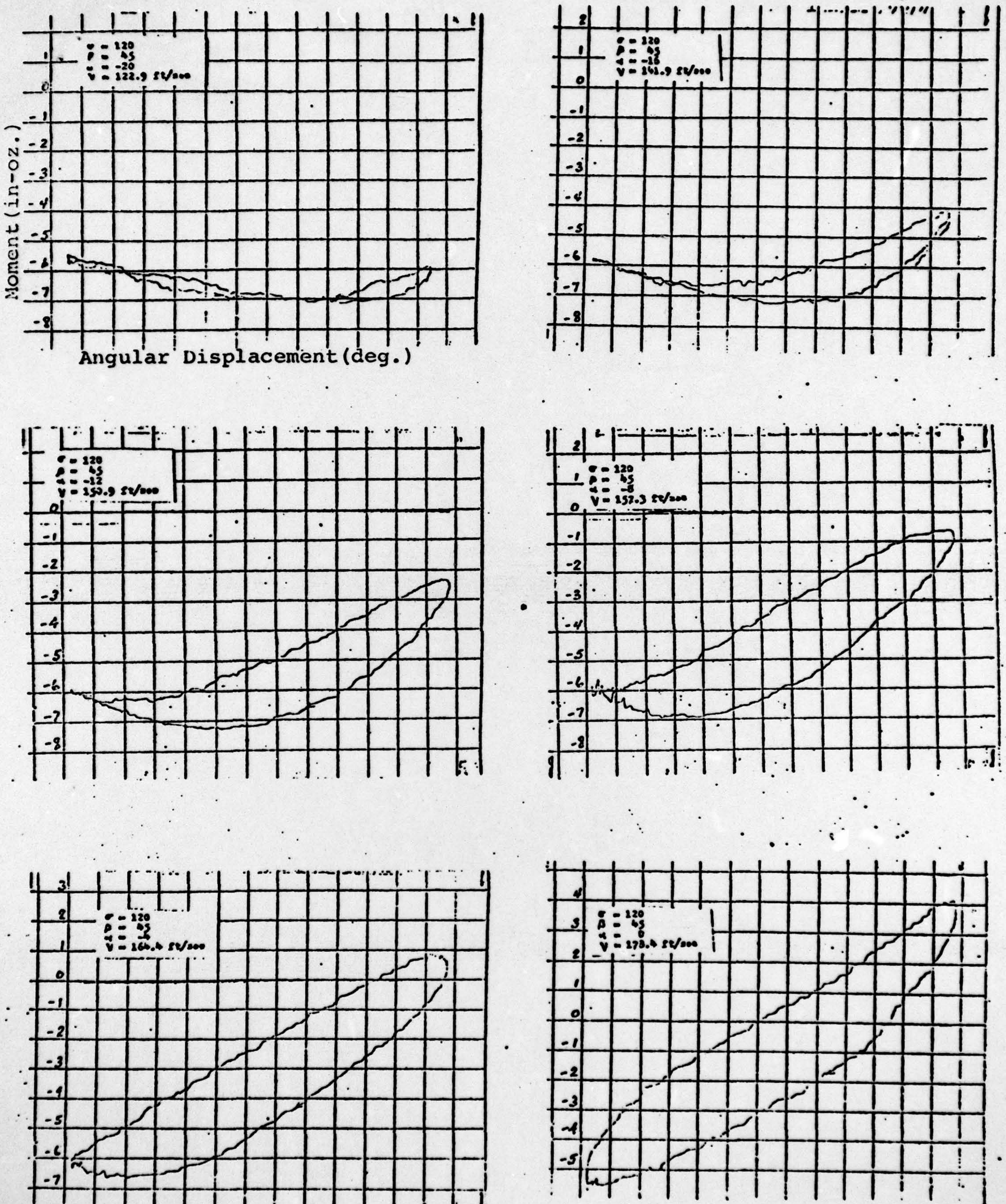


Fig. 15 Moment Loops for Large Amplitude with 120 deg. Interblade Phase Angle

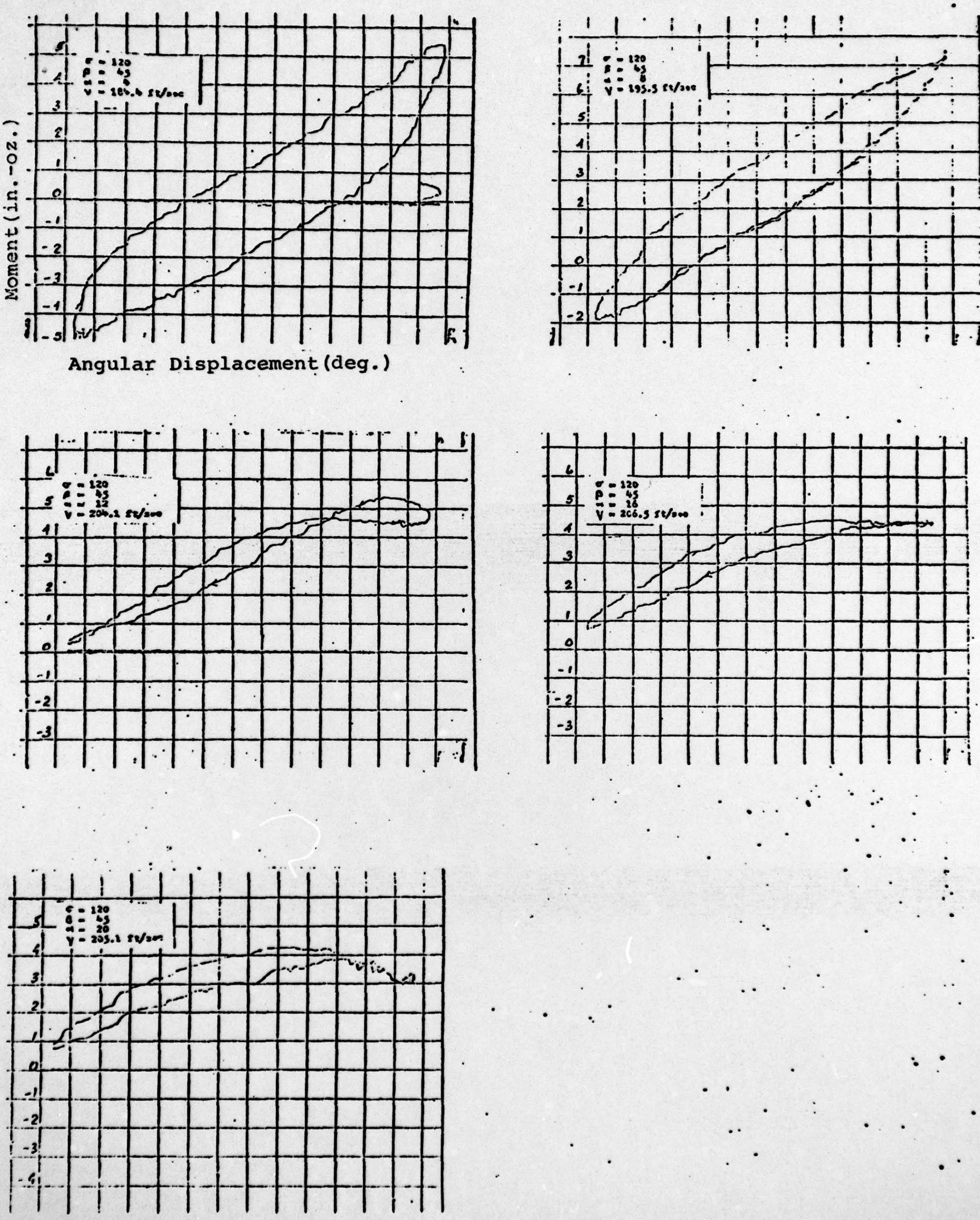


Fig. 15 Moment Loops for Large Amplitude with 120 deg. Interblade Phase Angle. (cont.)

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